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IN-FLIGHT SIMULATION-
THEORY AND APPLICATION

by

E. A. KIDD, G. BULL
and R. P. HARPER, Jr.

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IN-FLIGHT SIMULATION -- THEORY AND APPLICATION

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Edwin A. Kidd, Gifford Bull and Robert P. Harper, Jr.

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SUMMARY

This Report deals with the application of simulation techniques to the problems of determining aircraft handling qualities. Analog computers, fixed-base simulators, and various other ground machines are discussed. In particular, the theory and actual techniques of in-flight simulators of the variable-stability type are ~~dealt with~~. The conclusion is drawn that the solution of the various problems of handling-qualities requirements and of control system development requires the use of ground-based simulators *and* in-flight simulators as complementary tools.

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NOTATION

I	moment of inertia
L	lift
M	moment
q	angular pitch rate
α	angle of attack
β	angle of sideslip
δ_e	elevator control deflection
δ_{es}	elevator stick deflection
$\Delta()$	increment in variable
$\Sigma()$	sum of quantities
$\frac{\partial()}{\partial\alpha}$	partial derivative
$(\dot{\ })$	time derivative

Subscript

y	with respect to the y (pitch) axis

IN-FLIGHT SIMULATION - THEORY AND APPLICATION

Edwin A. Kidd, Gifford Bull, Robert P. Harper, Jr.*

I. INTRODUCTION

The general use of simulation techniques in aircraft handling qualities research, in the aolution of specific design problems, and in the development of new types of flight control systems, needs no justification. Analog computers, fixed-base simulators including cockpit and control mock-ups, and many other ground machines for simulation with various degrees of freedom, including centrifuges, have been employed for many years in these research and development areas. A most powerful and versatile tool that has been used extensively in handling-qualities research is the variable-stability airplane. Such aircraft with variable feel characteristics as well as variable static and dynamic characteristics about all three axes provide the best possible simulation short of flying the actual airplane being simulated. The evaluation pilot is actually in an airplane in flight. His control actions not only result in changes in his cockpit display, but also - and most important - in the proper angular rotations and linear accelerations. In addition to these physiological cues, the psychological 'set' of being in an aircraft where the consequences of pilot action can be serious is also present.

Some work and much speculation have been done regarding fixed-base vs in-flight simulation. There should be no controversy here. As long as pilots are flying aircraft and engineers are 'sweating out' flights, the proof of any theory or any design can only be achieved in flight. Speculations and postulations should rightly be investigated by theoretical analyses and fixed-base simulators. In-flight simulators of the variable-stability type can then provide the necessary flight verification. There are also areas of investigation in which it can become more difficult and expensive to accomplish meaningful results with fixed-based simulators. An example of such an investigation would be the determination of minimum handling qualities in visual landing approaches. In in-flight simulation the plethora of visual cues normally available to the pilot are there free of charge. Even to approximate these visual cues in a ground-based simulator is a complicated and expensive task.

The applications of this type of flight research will be discussed later. It is appropriate that first the theory behind such simulation and the actual techniques employed be discussed.

The variable-stability investigations discussed in this paper were sponsored by the U.S. Air Force and the U.S. Navy. The particular organizations technically responsible are the (1) Aeromechanics Branch, Flight Control Laboratory, Wright Air Development Division, U.S. Air Force, and (2) Stability and Control Branch, Airframe Design Division, Bureau of Weapons, U.S. Navy.

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2. THE 'HOW' OF IN-FLIGHT SIMULATION

The first topic for discussion concerns the means by which in-flight simulation is achieved. 'Simulation' is defined by Webster* as 'the act of assuming the appearance of, without the reality'. For our purpose this definition serves well, except that 'appearance' must be defined for the case of the pilot flying an airplane. In that regard, 'appearance' would seem to encompass the perceived response of the airplane to the pilot's control inputs. This perception includes both the static and dynamic response of the airplane, and in its complete form involves the entire six-degree-of-freedom motion.

If one airplane is expected to behave statically and dynamically like another airplane, then consideration of the Newtonian equations of motion shows that the coefficients of these equations must be similar. The parameters in the equations of motion which relate the moments to the angular accelerations and the forces to the linear accelerations must have a constant of proportionality between them.

If the pitching moment equation is written

$$\sum M_y = I_y \dot{q} \tag{1}$$

it can be seen that to match $\dot{q}(t)$ between the two airplanes requires that ΣM_y be matched if the moments of inertia are identical, or that $(\Sigma M_y)/I_y$ be matched if they are not.

The pitching moment can be expanded as follows:

$$\sum M_y = \frac{\partial M}{\partial \alpha}\Delta\alpha + \frac{\partial M}{\partial \dot{\alpha}}\Delta\dot{\alpha} + \frac{\partial M}{\partial q}\Delta q + \frac{\partial M}{\partial \delta_e}\Delta\delta_e \tag{2}$$

It can be seen from Equation (2) that in order to match $(\Sigma M_y)/I_y$, pitching moments (divided by I_y) must be applied to the simulator airplane proportional to α, $\dot{\alpha}$, q and δ_e in the same magnitude as in the airplane being simulated. If this can be done, the simulator airplane will duplicate the pitch response of the airplane being simulated.

The logical tool for applying the desired moments is the elevator of the simulator airplane. If the elevator is caused to move in such a manner as to match $(\Sigma M_y)/I_y$ of the simulated airplane, the desired simulation will be achieved. In order to match the α-dependent portion of $(\Sigma M_y)/I_y$, angle of attack of the simulator airplane is sensed (by a vane or probe, generally) and the elevator moved in proportion to it by the desired amount to match $(\partial M/\partial\alpha)/I_y$. In like fashion, $\dot{\alpha}$ and q are sensed and command incremental elevator motions to match $(\partial M/\partial\dot{\alpha})/I_y$ and $(\partial M/\partial q)/I_y$:

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* Webster's New Collegiate Dictionary.

It should be noted that the contributions of the simulator airplane's elevator motion due to α are supplemental to the $(\partial M/\partial \alpha)/I_y$ of the simulator airplane in matching $(\Sigma M_y)/I_y$. Hence

$$\left(\frac{\partial M}{\partial \alpha}\right)_{Desired} = \left(\frac{\partial M}{\partial \alpha}\right)_{Simulator} + \left(\frac{\partial M}{\partial \delta_e}\right)_{Simulator} \left(\frac{\partial \delta_e}{\partial \alpha}\right)$$

and similarly for the other derivatives.

In the airplane being simulated, elevator angle, δ_e, is generally a linear function of the pilot's control stick (or wheel) motion, δ_{es}. The term $(\partial M/\partial \delta_e)/I_y$, can be replaced by $(\partial M/\partial \delta_{es})/I_y$, the pilot's control motion sensed, and elevator angle commanded so as to match $(\partial M/\partial \delta_{es})/I_y$. Once this is done, then all the terms in the pitch equation of the simulator airplane match those terms in the pitch equation of the airplane to be simulated. If the same process of term-by-term matching is carried out on all six equations of motion, the response of the simulator airplane will duplicate that of the airplane to be simulated. The ailerons and rudder are used to generate the desired rolling moments and yawing moments, respectively.

Thus a variable-stability airplane is an airplane which utilizes its control surfaces to generate the necessary moments and forces to match the equations of motion of the airplane which it desires to simulate, and thereby responds to the pilot's input in the same manner as the simulated airplane.

The reader will undoubtedly be quick to note that the control surfaces of the simulator airplane are principally moment-producing and, if we are to match the force equations, we should provide force-producing surfaces on the simulator airplane which can be moved as a function of the force-producing response variables of the simulated airplane. Although this might be desirable for complete simulation, it is not often done, or is only partially done, due to the mechanical complexity required. All of the roots of the lateral and longitudinal characteristic equations can be altered independently without varying the force derivatives. However, only portions of the numerators of the response transfer functions can be altered independently without making use of variable force derivatives. Their exclusion is justified in the longitudinal case on the premise that the pilot is less aware of the aerodynamic angle $\Delta\alpha$, and normal acceleration is matched by permitting larger or smaller (but still proportional) changes in α than in the simulated airplane if $\partial L/\partial \alpha$ is not matched. This premise is reasonable only if there are not large differences in the force-producing capabilities of the simulator and simulated airplanes. In the current trend toward low lift-curve slopes and low dynamic pressure operations during the early stages of atmospheric entry, there is much concern over the effects of a large mismatch of $\partial L/\partial \alpha$ on the simulator evaluations. Variations of this parameter may be achieved by suitable operation of modified landing flaps or modified ailerons. It is well to point out here that appreciable variation in the force-producing derivatives of the simulator airplane is possible simply by altering the test condition of dynamic pressure.

We have now seen that one airplane can be made to fly like another airplane by utilizing the control surfaces of the simulator airplane to apply the necessary moments to match its equations of motion to those of the airplane to be simulated.

The control surfaces of the simulator airplane are thus moving constantly in maneuvering flight. If the pilot were to feel all these movements, the simulation would not be realistic to the pilot. Therefore, he is provided with an artificial feel system mechanically separated from the control surfaces which are positioned by irreversible electro-hydraulic servos. In airplanes in general, the pilot does not directly perceive his control surface positions; he assumes they are directly related to his control stick and rudder pedal positions. In the simulator airplane, he is totally unaware of the artifice used in introducing the added control motions.

The design requirements of the control surface servos are stringent. They must be fast-acting in order to minimize the time delay between sensing a response variable (e.g., $\Delta\alpha$) and applying the moment to the airplane. They must at the same time retain reliability for flight operation. The Cornell Aeronautical Laboratory designs special servos for this purpose, and those on the T-33 variable-stability airplane all exceed 10 cycles/sec natural frequency while maintaining excellent reliability.

A versatile artificial feel system is used to provide ready variations of the type, form and proportional amounts of each possible type of control feel. Forces can be provided proportional to control displacement, velocity, and acceleration and to any response motion of the vehicle, such as normal and rotational acceleration. Breakout forces and control centering springs can be represented to further the simulation.

The airplane response motion sensor requirements are high, as one might expect. Since the response motions of the airplane are used as commands to the surface servo to alter the handling characteristics dynamically as well as statically, the sensors must accurately relate the airplane motions to the variable stability system. Single-degree-of-freedom rate gyros sense the angular velocity about each axis. Angular accelerations are obtained by differentiating the gyro outputs. Chopper differentiators[1] are used which have 45° phase lag break points (including filters) in excess of 10 cycles/sec. Airstream directions are sensed by vanes or probes. Herein lies a problem area which serves to bound the extent to which the handling characteristics can be altered. Vanes are preferable because of their generally high natural frequency and minimum phase lags, but due to their deficiency in damping they are relatively poor elements in a control loop. The airstream direction sensor probe has fine damping qualities, but lacks the high natural frequency of a good control loop sensor. Prandtl tube sensors of airstream direction contain a relatively high level of atmospheric 'noise' and must be filtered so heavily as to considerably reduce their basically rapid response characteristics. What is needed is a high natural frequency vane of the type presently in use which incorporates a means of increasing the damping to an acceptable level. This damping requirement is complicated by the variation in vane natural frequency with dynamic pressure so that in order to maintain constant vane damping ratio, the vane damping must also vary approximately with dynamic pressure.

Precision accelerometers are used to sense normal and side acceleration. Early in the development of the T-33 variable-stability airplane, angle of attack and sideslip angle were derived in flight using the normal and side accelerometers, respectively, to compute α and β from the normal and side force equations. However, the susceptibility of this method to structural-frequency inputs caused

this method to be of doubtful usefulness in a control system, and recourae waa made to the direct measurement of α and β with vanes and probes. The accelerometers are now used for recording purposes and for data inputs to system safety circuits.

Further details of the specific variable-stability systems are left to the reader to obtain from the references at the end of this Report. Some additional concepts should be discussed, however. The safety aspects of the variable-stability airplane are important, for herein lies one of its principal attributes. Properly designed, it has the capability of allowing the pilot to examine, in flight, situations which appear marginally controllable, and to make an in-flight evaluation prior to undertaking the risks of flight testing the actual, expensive piece of machinery. This is designed to be a safe operation with the variable-stability syatem by providing for instant return to the basic simulator airplane's handling characteristics when the variable-stability system is deactivated. The system is monitored and automatically deactivated by a variety of devices which include:

1. Normal and side acceleration limiter circuits

2. Control surface servo error signal limiter circuits

3. Monitors of the various electrical power sources

4. Monitors of the system hydraulic pressure.

In addition, both pilots - the evaluation pilot and the safety pilot - have available push button switches which will deactivate the system. Thus if the evaluation pilot loses control of a particular simulation configuration, control of the airplane is returned to the safety pilot simply by pressing a button, and he has good handling characteristics with which to recover from any unusual attitude.

The safety pilot is an important part of the in-flight simulator concept. His duties are many. He

1. sets up system configuration gains and activates variable-stability system,

2. monitors pilot and system performance, and takes control of airplane whenever required,

3. manages the wire recording of evaluation pilot comments and oscillograph recording of in-flight calibration and performance-measuring maneuvers,

4. manages basic flight operations, fuel sequencing, navigation, etc., and

5. maintains lookout watch for other air traffic for collision avoidance.

It can be seen that the safety pilot is busy during an evaluation flight. This is the principal reason that most of the later generation of variable-stability airplanes are two-place. To require the evaluation pilot to assume the roie of safety pilot and system manager in addition to his evaluation duties has proven unwise. Evaluation is a difficult task requiring the complete attention and concentration of the evaluation pilot. To burden him with the additional duties of the safety pilot in a single-place airplane is to compromise seriously flight safety as well as the quality of the evaluations.

The discussion thus far has indicated some of the basic concepts of in-flight simulation. The basic technique is the matching of the static and dynamic forces and moments of the simulator airplane to those of the airplane being simulated. What then are some of the requirements for the selection of the basic simulator airplane? It should be two-place. It should be relatively simple to operate from a functional standpoint to minimize cost and maximize reliability. It should have relatively linear force and moment characteristics. If the airplane to be simulated has non-linear characteristics, it is much easier to incorporate these in the variable-stability system than it is to remove them from the basic airplane in order to simulate a linear airplane.

To these basic requirements can be added many desirable features which will minimize the cost of achieving the desired simulation. For example, if it is a jet type simulating another jet type, then the need for additional equipment to reproduce the engine acceleration characteristics may be eliminated. This list could be expanded, but in the interests of brevity, the reader will be left to devise his own.

The CAL T-33 variable-stability airplane which has been mentioned before has proven to be a good choice for the general simulation task. It satisfied the above-mentioned requirements, and has many other desirable features. One such feature was the capability for installation of a larger (F-94A) nose section in place of the standard T-33 nose. This reduced the requirements of component miniaturization, decreasing the cost and increasing the system reliability. Photographs of this particular airplane and the variable-stability installation are presented in Figures 1 to 3.

In addition to the basic system for in-flight simulation, a number of sophistications are currently in use or being added to present equipment. Equipment has been designed which permits the coefficients in the equations of motion (i.e., the variable-stability system gains) to be varied automatically as functions of time, thus permitting the simulation of maneuvers such as re-entry, in which the handling characteristics vary with time. Variable-drag devices are presently being installed on the T-33 which permit the matching of the coefficients in the X-force equation, and which make possible the simulation of the descent flight path of the low L/D entry vehicles. This flight path simulation may be accomplished simultaneously with simulation of the handling characteristics. Figure 4 presents the drag devices as installed on the tip tanks of a wind tunnel model.

The capability of operation as a high-fidelity ground simulator has been incorporated. In this use the simulator airplane is plugged into an analog computer which receives the actual airplane control surface deflections as the computer inputs. The analog solves the six-degree-of-freedom equations of motion for the response motions of the airplane. These motions are fed back to the cockpit display instruments and to the variable-stability system. Hence, the variable-stability airplane 'flies' on the ground in the same manner that it flies in the air. A variety of pilot input controllers are in use, including center stick, center control wheel, two-axis side stick and three-axis side stick. The cockpit instrument displays use both standard and special display instruments as the simulation requirements dictate. Pilot controllers and the cockpit display instruments are shown in Figures 5 and 6.

The ultimate capabilities of the in-flight simulator have only been touched on to date. The concept has been proven both valid and realistic. The need for in-flight simulation

seems to grow each year as flight vehicles become more complex, expensive and farther-reaching in their operating environment. The first flight of such a vehicle must be successful. It is invaluable to have first-hand, in-flight experience with the vehicle handling characteristics - whether it is a supersonic airline transport, or the 'big shoot' into space.

3. TEST TECHNIQUE FOR FLIGHT EVALUATIONS

A full appreciation of the utilization of the variable-stability airplane as a flying simulator requires knowledge of the techniques employed in conducting research with these aircraft. In obtaining pilot rating data, care must be taken to insure that the ratings are objective and consistent. Particular experiments must be conducted in a fashion which will best remove known sources of bias. Accurate knowledge of the configurations evaluated is a must. That is, the values for *all* stability and control parameters for each configuration evaluated must be determined - preferably from analysis of actual airplane responses obtained during each evaluation.

These ground rules are not stated just to emphasize a position against sin. They are essential in order that consistent, repeatable, objective pilot ratings and comments can be obtained. A discussion of the methods utilized in implementing these ground rules follows.

3.1 Selection of Variables

The variables in any handling qualities investigation should be those which describe the airplane motions and control forces and motions as perceived by the pilot. Thus, it is generally necessary to vary lumped parameters of particular transfer functions rather than individual stability derivatives. Variations in the latter may affect more than one aspect of the motion. Examples of variables which describe the motion in terms which the pilot also seems to recognize are period and damping of oscillatory motions, times to double or half amplitude of exponential motion, control forces and motions, ratios such as stick force per steady normal acceleration, roll amplitude per yaw amplitude in the lateral-directional oscillation, steady roll rate per aileron force, and the like.

3.2 Data Gathering Program

When sufficient preliminary knowledge exists, a program can be designed to produce maximum information from the experimental effort. The preliminary knowledge may come from an exploratory type of program, or from experience acquired in operational use. The final analysis of the data is likely to be statistical in nature, particularly if measures of the intra and inter pilot variability and of the accuracy and reliability of the results are desired. Therefore, the experiment is designed according to established statistical procedures with attention to number of subjects and number of trials, repeat points, randomization of the order of presentation of the different configurations for the pilot to evaluate, and so on. Randomization is important, to minimize the influence of past configurations upon the pilot's rating of the next configuration. For example, a mediocre configuration might be rated as 'good' if it followed a poor configuration and 'bad' if it followed a good one.

3.3 Form of the Data

In handling-qualities investigations, is usually appears to be possible to measure the effect of a variable upon the performance of some task, such as tracking. Alternatively, instead of measuring the actual performance, the pilot may be asked to rate the airplane in terms of its suitability for the task. At first glance, the quantitative measure of task performance would seem to be clearly preferable, since it yields an incontrovertible measure of how well the task was performed, no matter what the pilot's opinion was. Quantitative data are generally more respectable and more satisfying to engineers. Furthermore, they are amenable to mathematical manipulation. However, experience in handling qualities studies has shown that such quantitative data must be used with great caution. Apparently a pilot can compensate for large deficiencies in handling characteristics, and maintain his ability to perform a task even though the airplane has been made quite suitable. His comments or ratings of the airplane provide the only indications of the degradation of the bandling qualities. Since his task performance scores may not be affected by the variable which is altered, it may be argued that the variable is not in fact important. However, the pilots may be (and usually are in such cases) firm in their opinion that tbe degradation of the handling qualities did truly make the airplane less useful. Tbey acknowledge the fact that their task performance did not suffer, but claim tbat in the presence of stress, fatigue, or distractions they could not have maintained the performance. Figure 7 presents the results of one type of performance measure obtained for three different longitudinal dynamic configurations as a function of stick displacement per normal acceleration. The pilot task was to minimize pitch disturbances due to an applied random elevator deflection while maintaining straight and level flight. There is little or no correlation between the trend of this performance measure and that of the pilot rating data in the second part of the figure. Attempts have been made to perform tests with a controlled amount of distraction[2] but it is not yet possible to put great confidence in the reliability of results obtained with distraction or simulated stress.

In handling-qualities tests, it is not always easy to know what parameters to include in a quantitative measure of the performance of a task. Variables which are important may be neglected. In forming his opinions, the pilot will tend to include all the relevant factors, including any which the test conductor overlooked. Pilot comments can point the way to a separation of the variables, and perhaps eventually to tbe design of a reliable quantitative test.

To summarize, a quantitative measure of task performance seems desirable, and a worthy goal, but the state of our knowledge at present requires careful attention to pilot opinion data. If task performance data conflict with opinion data, the performance data should be viewed with great suspicion.

3.4 Selection of Subjects

The experience level of the pilots who will serve as subjects for an investigation will depend to some extent on the purpose of the particular investigation. For example, an investigation to determine the effect of some variable on the ease of learning to fly would necessarily involve student pilots. In the work reported in Reference 3, both neophyte and experienced gunnery pilots were used to determine the effects of Dutch roll damping on tracking and actual gunnery. However, experience

in a number of handling-qualities investigations at the Cornell Aeronautical Laboratory has demonstrated that pilots of various backgrounds show remarkable unanimity of opinion in many aspects of the handling qualities of airplanes. There is some feeling that rating an airplane for operational use should be done by operational pilots. Again, experience has shown that data obtained from experienced test pilots will agree with data from operational pilots[4,5]. Pilots generally give ratings consistent with those from other pilots when they are rating a stability configuration as it applies to themselves, rather than how they think it applies to pilots of other experience. For example, experienced pilots may rate a configuration as marginally acceptable for themselves, but unsuitable for inexperienced pilots. If inexperienced pilots then rate the configuration, they will tend to agree with the ratings given by the experienced pilot rather than the rating which the experienced pilot predicted they would give. It is emphasized that we are referring here to the handling of the airplane rather than the judgment and decisions required in flying.

The number of pilots required to yield reliable data is a subject which leads to considerable discussion. In some fields of investigation, reliable results apparently can be obtained only from a sizeable number of subjects. Experience at the Cornell Aeronautical Laboratory, in some flight investigations using data from a large number of pilots, has shown that there is surprisingly little difference of opinion, and that a small number of pilots would have sufficed[4]. Usually there is insufficient money and time to carry on flight tests with large numbers of subjects, and many investigations have been performed by only a few pilots. It has been our experience that experiments using detailed investigations by a few pilots yield more information for the money than less detailed investigations by a large group of pilots. The evidence has not shown this practice to lead to large errors. Apparently, humans do not differ markedly in their ability to function as sensing and servo mechanisms, although the wide range of their political, social and artistic opinions is only too well known.

3.5 Inter Pilot Variability

It is interesting to compare pilot ratings from some specific investigations. In all of the comparisons to be discussed, except the last, the pilot ratings were obtained with adjective scales. These scales have been converted to the ten-point numerical scale assuming a linear correlation.

Two pilots evaluated the effects of variables in the damping of the spiral mode on pilot ratings and comments in instrument and visual flight[6]. Individual ratings were obtained for each of several specific tasks at different values of spiral damping. Each damping configuration was repeated with each pilot. In Figure 8, the mean rating at each value of damping is plotted for one pilot vs the other. The agreement is quite good, as indicated by the smaller scatter about the line of exact agreement. One of these pilots was an experienced test pilot, the other an engineer with considerable piloting experience but little test piloting experience.

A three-pilot comparison is presented in Figure 9 for an investigation of the effects of variations in stick displacement per normal acceleration at different values of longitudinal short-period frequency and damping and different values of breakout force[7]. Pilots A and B were experienced test pilots, although with

considerable difference in aircraft types flown. Agreement between these two was fair, as indicated in Figure 9(a). Pilot C was a less experienced test pilot and also less familiar with the objectives of this type of evaluation. In addition, there was some difficulty in establishing rapport regarding the rating scheme. This is evident in Figure 9(b), where a least squares fit would have a slope of approximately two instead of the desired value of one.

A three-pilot evaluation to establish desirable longitudinal dynamics, short-period natural frequency and damping[8], resulted in the comparison in Figure 10. There is little to choose between these comparisons - each indicates good agreement. Some of the scatter may be due to the fact that few of the rated configurations were exactly the same from pilot to pilot. Small differences existed both in damping and in frequency - no greater than ±0.05% of critical damping and ±0.05 cycles per second of natural frequency.

The three-pilot comparison shown in Figure 11 is from an investigation to establish minimum longitudinal handling qualities in landing approaches using a mirror landing aid system. Atmospheric turbulence was definitely a variable in this program. The comparison of pilots A and B is shown for relatively smooth air while the small number of comparative data available for pilots B and C is for rough air. Both ratings of turbulence are subjective ones by the safety pilot - the same pilot for all evaluations. Pilots A and 8 had comparable flight test and carrier landing experience with considerable difference in total flight time. Pilot C had considerable more flight test time with no carrier landing experience. More data points were available to establish the minimum flyable boundary but only those shown in Figure 11 were sufficiently close to the same values of longitudinal dynamics to make the rating comparisons.

The last comparison concerns a fixed-base simulator investigation utilizing the variable stability T-33 coupled with an analog simulation of the basic T-33 aerodynamic forces and moments. This program, under the sponsorship of the Flight Control Laboratory of Wright Air Development Division, U.S. Air Force, is currently in progress and will include an in-flight investigation to check the fixed-base simulator results. The data available to date include both longitudinal and lateral-directional evaluations to investigate minimum flyable configurations and intermediate configurations between acceptable and unflyable. Figure 12 presents the comparison between two pilots of similar total experience. These data are preliminary in that continuing data analysis may show some configurations, assumed the same for each pilot, to be different. The analysis now in progress will establish the configurations evaluated.

The quantity of data available here lends itself to some statistical analysis. A least-squares fit of pilot B on pilot A provides a slope of 0.88. Similarly, a fit of the data from pilot A on pilot B indicates a slope of 0.91. These least-squares fits are indicated on Figure 12. The variation from the line for exact agreement is fairly small. The sample standard deviation from each of the least-squares fits (regression lines) is 1.2. As these two best fit lines are quite close, it comes as no surprise that the standard deviation in pilot rating about the line for exact agreement is also 1.2.

The points grouped about ratings of 10 and 10 on Figure 12 should not be used in this type of statistical analysis. The rating scale is such thst a rating worse than 10 still receives a rating of 10. Using these points for such a bounded scale biases the data. In this particular case, the bias is negligible.

This brief analysis of the data of Figure 12 is indicstive of the statistical measures that can be obtained with sample sizes that are not usually available in this work. More data will become available from this investigation and from a flight investigation being conducted at Patuxent River, Maryland, for the U.S. Navy.

3.6 Pilot Orientation

An essential factor in obtaining consistent ratings between pilots is proper orientstion for the particular evaluation. Each pilot must be thoroughly briefed on (1) the mission of the aircraft or type being considered, (2) the maneuvers that will be flown as representative of this aircraft and mission, and (3) the rating scale to be employed. The first of these should point out the general requirements; e.g., is a re-entry task being considered, is an emergency VFR landing approsch the only tssk, or is enroute IFR flying the flight condition to be evsluated? Whether maneuverability is a prime requisite or precise control a necessaity are questions that must be discussed. In this manner, a frame of reference for the evaluation is established.

A standardized rating scheme is necesssry; whether numbers, letters or words are used is not important. A numerical scale, such as the 'Cooper Scale'[9], is now widely used. This ten-point scale appears to provide enough resolution for adequate expression of ratiogs without having so many possible ratings as to produce over-lapping. The adjective scale employed earlier at the Cornell Aeronautical Lsboratory is approximately convertible to this ten-point scale. The number scsle now used includes the final rating 10 as unflyable, not as "!!"", as Mr. Cooper ststed it. There has been a tendency to allow this rating scale to furtber strophy in some usage[10] in that a rating of grester than 8 is considered unflyable. For the results of evaluation programs to be readily comparsble, uniformity in scales is desirsbls. Terminology, in ratings and comments, should be clear to all concerned. It is important to be explicit here, since the pilot and the analyst may assume different interpretations of a word or phrase. Pstience and persistence may be required to reach a meeting of minds on termioology. The pilot sbould be encouraged to givs comments in whatever language is most expressive to him. Psychologicsl, msthematical, engineering, pilot talk, slang, or plsin descriptive terms are all acceptable - ss long as mutual understanding exists.

3.7 Data Collection Techniques

Pilot opinion information hss its own difficultics for the analyst. Termioology is critical. Words may have different meanings to different people. The opinion may be expressed vaguely, as 'it flies funny'. It is sometimes hard to translate opinions into engineering terminology and concepts. Linearity is difficult to establish and may not exist. For example, what does 'twice as bad' mean? Experience with collecting and handling opinicn data has led to methods for minimizing these difficulties.

Comments should be obtained while the impressions are still vivid in the pilot's mind. A wire recorder encourages copious comments, because it is easier and faster to talk than to write.

A standardized set of maneuvers should be used, selected to show all the pertinent aspects of the airplane handling qualities affected by the variable in question. The pilot should be permitted any free maneuvers he chooses, in addition to the standard set.

A comment card should be used to force a comment on each of these aspects. Otherwise, if a comment is missing, the data analyst cannot tell if it was important but overlooked, or if it was unimportant. It also serves as a check list for the pilot, to remind him to look at each item. The rating scale, with definitions, should be in front of the pilot while he is recording his comments and ratings to aid in standardized ratings.

Comments should be given in terms of how the behavior of the airplane appeared to the pilot, how it affected his ability to perform his task, and why. Comments should provide the raw data. If the pilot then has an interpretation, analysis or hypothesis, he is encouraged to give it, but raw data in the form of a direct description of his ability to control the airplane are essential. His analysis may be faulty, but his observations probably are not.

4. DATA ANALYSIS

The data from handling qualities tests, whether they are a measure of performance of a task or pilot rating, are plotted to show the goodness of the configuration as a function of the quantity being varied. Frequently two variables are known to be interrelated. Regions on the plot for which the ratings were the same are delineated, forming an 'iso-opinion' plot. An example is given in Figures 13 and 14. It should be noted that a given rating may be applied to different regions of such a plot for quite different reasons. In Figure 13, for example, one region may be rated 'unacceptable' because the airplane's response is too sluggish, and in another region, the same rating may apply because it is too lightly damped.

Comments serve several purposes in analysis of the data. They serve to confirm the ratings. The analyst may place more confidence in a rating which is supported by the comments than in a different rating of the same point which is at variance with the comments. The comments may reveal unsuspected variables in the experiment, or suggest that factors which were felt to be unimportant were, in fact, important. Also, the comments tell why some aspects of the handling qualities received a certain rating. From this information, it may be possible to further break down the variables affecting the handling qualities, and set up tests on these newly isolated variables. Examples of this process are discussed in Reference 11. A major use of the comment data is to assist in drawing boundaries between regions of interest of the pilot rating data or in establishing functions of ratings vs particular variables. Often, insufficient points are obtained to define adequately such functions. Extensive pilot comment data provide information for interpolating between discrete rating points and in some instances, even extrapolation beyond an existing rating.

4.1 Determination of Characteristics Evaluated

The attainment of good pilot rating or over-all performance data comes to naught if the configurations evaluated cannot be described accurately. Such description can best be obtained through analysis of pertinent airplane responses to control inputs as recorded in flight at the time of the particular evaluation. If variable-stability system gains can be precisely defined for the operating temperature range; if the effects of component aging can be accounted for with sufficiently frequent calibrations; if the variations of the airframe being used as a simulator are known precisely as a function of airspeed, altitude and center-of-gravity position; if the anomalies that plague power supplies, amplifiers, transistors and other electronic components (even wiring) can be legislated against; then the characteristics to be evaluated can be calculated with assurance and used with impunity as those that existed during the test. As these factors are pertinent, it is essential that in-flight calibrations be conducted to determine the stability and control characteristics as functions of the various system gains. Such calibrations accomplished throughout a particular investigation will greatly increase confidence in the results. Analysis of these calibration records is an important part of any simulation program.

Configurations with a discernible period and moderate damping can be established as regards frequency, damping, and static gains with normal transient response analysis techniques. Even here it is often impossible to measure such parameters as roll-to-sideslip ratio and completely impossible to measure specific numerator functions of particular response transfer functions. Heavily damped configurations or those that are divergent as a result of negative static margins or negative damping are not amenable to even this type of analysis. The 'equations of motion' technique developed some years ago and used with success in the flight determination of stability derivatives shows promise for this problem. It is presently being used to analyze flight measured responses of the CAL variable stability T-33. With this method the pilot remains in the control loop (and thus can stabilize divergent configurations) and performs maneuvers to excite the various modes of motion. Digital computer analysis of the time-histories of control deflections and airplane responses solves for the coefficients of the complete equations of motion and accomplishes a least-squares fit to these coefficients. Machine calculations then determine the stability and control parameters from these values of the coefficients. This method including the IBM programming is described in detail in an as yet unpublished report by Harper.

5. APPLICATIONS

A major application of simulators that fly is in general research on handling qualities. Much work has been done in this area and more is in progress. This work supplies fundamental knowledge of how pilots fly airplanes and provides invaluable information for establishing handling-qualities specifications. In general, such specifications apply to particular types or classes of aircraft. With proper selection of maneuvers to be flown by the evaluation pilot, the over-all mission of particular aircraft types can be simulated in flight and both the desirable and minimum handling-qualities requirements can be established. Examples of this type of research are presented in the references. The earlier investigations were aimed primarily at establishing desirable requirements and at discovering those parameters most important

in the pilot control of an aircraft. It is interesting to note that in the work of References 11 and 12, the importance of longitudinal short-period natural frequency was first recognized. Prior to this time, concern with improving the handling characteristics of specific aircraft had taken the form of damping augmentation. Pilot-induced oscillations were thought to be the result of the particular control system rather than of the inherent airplane characteristics. As is now well recognized, it was determined that even with adequate damping of the longitudinal short-period mode, there were upper and lower limits on acceptable frequency.

Task-orientated applications are as many and varied as the specific tasks that airplanes are required to accomplish. These include tracking of other aircraft or ground targets, enroute instrument flight, re-entries, and instrument and visual landing approaches. Examples of this particular research are presented in References 2,3,6,13,14 and 15. The importance of the task to be accomplished by the pilot-airplane combination has become quite apparent in the research to establish minimum handling-qualities boundaries. It is one thing to keep an airplane right side up in cruising flight from one point to another; it is quite another problem to accomplish a successful landing approach with poor handling characteristics about all three axes with the added complication of required, precise flight path control while coping with low lift-drag ratio and high approach speeds. In-flight simulation through the use of variable-stability techniques and variable lift-drag capabilities offers a unique ability to investigate these specific tasks in approximately the same over-all environment as the actual vehicle and with a great increase in safety. A good example of this is the work reported in Reference 14. Actual mirror landing approaches were accomplished down to approximately 10 feet of altitude (or less) with no dangerous incidents. During these approaches the pilot coped with longitudinal characteristics that were quite divergent - in order to establish minimum handling qualities. This flight evaluation was not considered hazardous as it was always possible for the safety pilot to take over the normal airplane immediately with its 'good' handling characteristics in the event that the evaluation pilot got into difficulty. It is this ability to revert to a relatively good aircraft that allows research into such normally unlikely handling characteristics areas.

The goal of general research on handling qualities is to provide the aircraft designer with an adequate background of data, so that design decisions can be made with confidence. At present, this confidence level is rising and will continue to rise. However, the very fact that a new aircraft is being designed normally means that new mission requirements are being met. New and different tasks to be accomplished by the pilot-airplane combination are to be considered in the design phases. Also, compromises between performance and handling qualities may be required. These factors can result in the need for more specific information in areas not quite adequately covered in general handling-qualities research. Thus there will continue to be a need for ad hoc problem solving during the design and development phases of a particular aircraft. A flying simulator facility can provide solutions to such problems quickly and with essentially as much confidence in the results as if the work were accomplished on the actual aircraft itself.

Some use has already been made of variable-stability flying simulators in pilot training and familiarization. Before the initial flight of one particular airplane, the estimated longitudinal stability and control characteristics of the airplane were simulated with a variable-stability airplane[7]. This particular work served two

purposes. General information regarding the effects of control stick motion per pilot applied force was obtained. Also, the pilot who was to make the initial flight of the particular airplane simulated familiarized himself with the handling qualities of the airplane in various flight régimes. This use of flying simulators in showing the pilot the vehicle he will have to control is particularly valuable for aircraft with low inherent stability augmented with various stabilizing devices. In the event of stability augmentation system failure during the initial flight, the pilot can quickly utilize those control techniques developed in the flying simulator. The learning required has already taken place in a safe vehicle that nevertheless accurately simulated the actual aircraft. The first flight of a new airplane is not usually the best place to experiment with control techniques.

Another use of a flying simulator as the final step in pilot training for a unique aircraft and a unique flight régime was the recent variable-stability T-33 simulation of the X-15 re-entry. Here, six pilots already trained on fixed-base simulators and centrifuges flew simulated X-15 re-entries in the actual acceleration environment and with the estimated X-15 handling characteristics throughout the re-entry. In this particular case, the evaluation pilot took over flight of the T-33 in a zero g environment, accomplished the initial rotation of the airplane to the proper angle of attack and subsequently made an instrument re-entry, with the gradual build-up of normal acceleration occurring just as it would in the X-15. This simulation of the varying characteristics of the X-15 was accomplished through suitable programming of the variable stability system of the T-33 and the special instrument displays which also simulated those of the X-15.

The Navy is now using an in-flight simulator to assist in the training of pilots at the Naval Test Pilot School at Patuxent River, Maryland. This work is being accomplished by the Cornell Aeronautical Laboratory and sponsored by the Stability and Control Branch, Airframe Design Division, U.S. Navy Bureau of Weapons. The program is proving quite successful in that the trainee pilots can see and fly wide ranges of handling qualities, including unstable values, and thus get a concrete appreciation for their theoretical courses in stability and control. The ability to vary one parameter at a time allows the trainee to see the effects of different variables and leads to a clearer understanding of stability and control. The purpose of this particular program is primarily education to help Naval test pilots in their task of testing and evaluating Naval airplanes. In one airplane and on a single flight, the pilot can become intimately acquainted with the characteristics of many airplanes. He can also fly characteristics which are most suitable for particular tasks and those which are definitely unacceptable or obviously unflyable.

A logical extension of these pilot training applications is the use of flying simulators to maintain pilot proficiency and pilot training for operation of modern jet transports. Such training involves flight in various emergency conditions which inescapably increases the possibility of damage or loss of equipment. This factor, coupled with the loss of revenue resulting from use of an airplane for training purposes, makes it attractive to use a substitute for the airliner for training to the maximum extent possible. Ground-based simulators are widely used for these reasons. These simulators have been developed to the point where they provide excellent training in cockpit procedures and in instrument flying and in navigation. Many emergencies can be simulated adequately, to give the flight crews practice in detecting troubles and taking the appropriate action to deal with them.

However, the correct procedures for situations in which the actual flying characteristics of the airplane are important are best learned in actual flight. Therefore, transition training and periodic proficiency checks are given in the actual airplane, where both normal and emergency procedures are practiced. Ths high cost and increased hazard to the airline for this use of such a productivs airplane makes it desirable to find a substitute, similar to the ground-based simulator, for some of this flying. Such a substitute exists in the form of the variable-stability airplane. There is an added bonus of increased safety in the use of such a flying simulator for practicing emergency procedures. If a trainee pilot uses improper technique and the situation becomes difficult, the safety pilot can disengage the special variable-stability equipment within a fraction of a second. Immediately, the airplane is restored to its good, normal handling qualities, the safety pilot can control it through its normal controls, and the training can begin again. The in-flight simulator would not replace the ground simulator - it would complement it.

In addition to general research on handling qualities and the simulation of specific vehicles, the variable-stability flying simulator provides an excellent tool for research on specific control systems. Due to the fact that the evaluation pilot's controls are completely separated from the airplane's and his only input to the airplane's control system is electrical, pilot force inputs or control deflection inputs may be used to order any desired vehicle response. For example, fixed control, that is, force inputs only with no control deflection, can be investigated with either center stick or side controller. Any particular type of control can be investigated over the full spectrum of possible handling characteristics, both longitudinal and lateral-directional.

Specific stability augmentation systems may be evaluated with the variable stability airplane. For example, the performance of 'adaptive' concepts can be determined in a representative flight environment with the attendant sensing element and structural noise inputs and with selected critical dynamic and static characteristics.

6. CONCLUSION

To summarize, there is still work to be done in the establishment of handling-qualities requirements and control system development. Ad hoc problems in particular airplane design developments will need to be solved. Knowledge of human control capabilities in new and demanding flight régimes is required. The difficulties in obtaining adequate pilot familiarization, training, and proficiency maintenance in the new types of high-performance aircraft are increasing. The solutions to these problems require the use of ground-based simulators and flying simulators as complementary tools. Each has special virtues which should be carefully and fully exploited.

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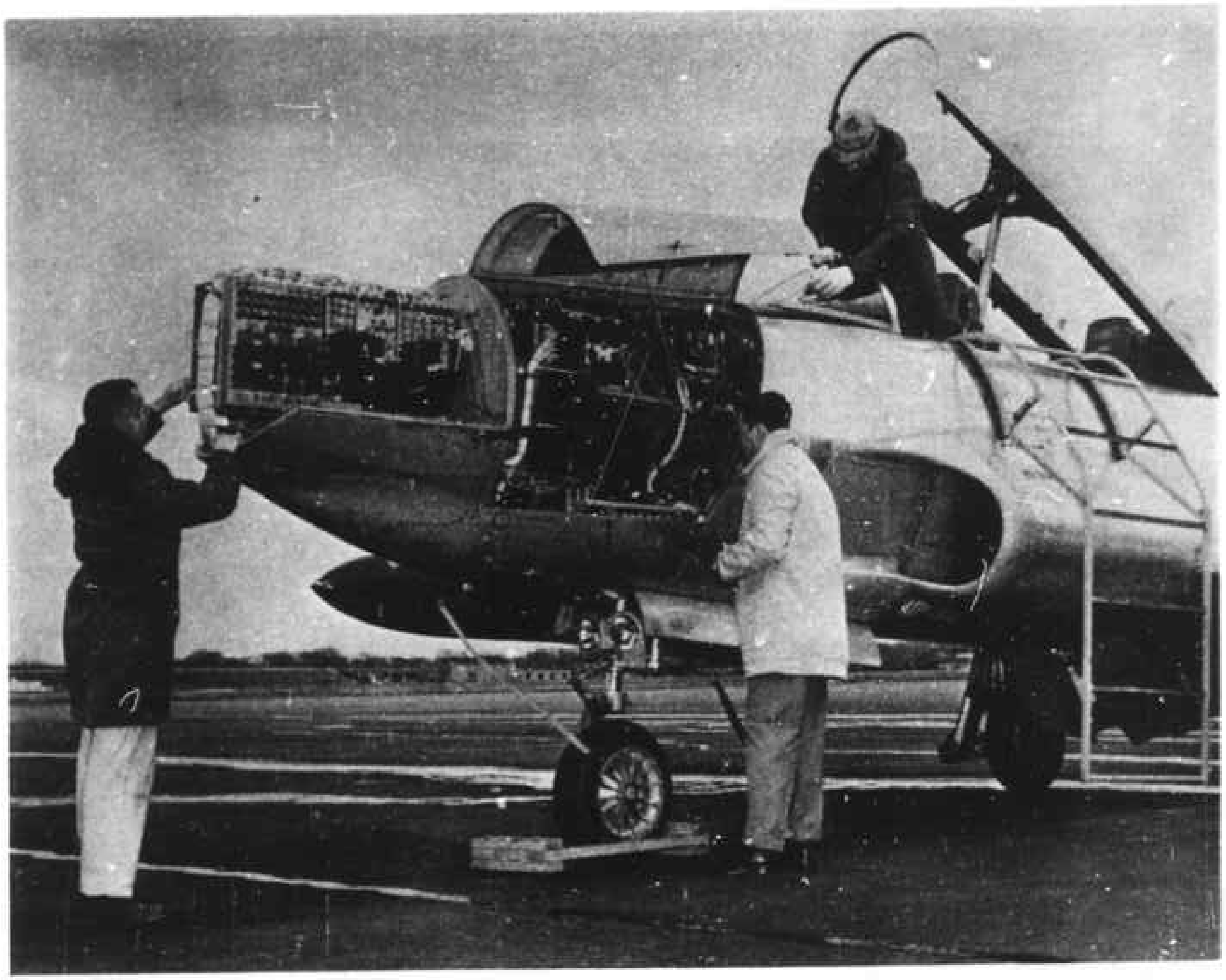


Fig. 1 Variable-stability installation in nose section of T-33

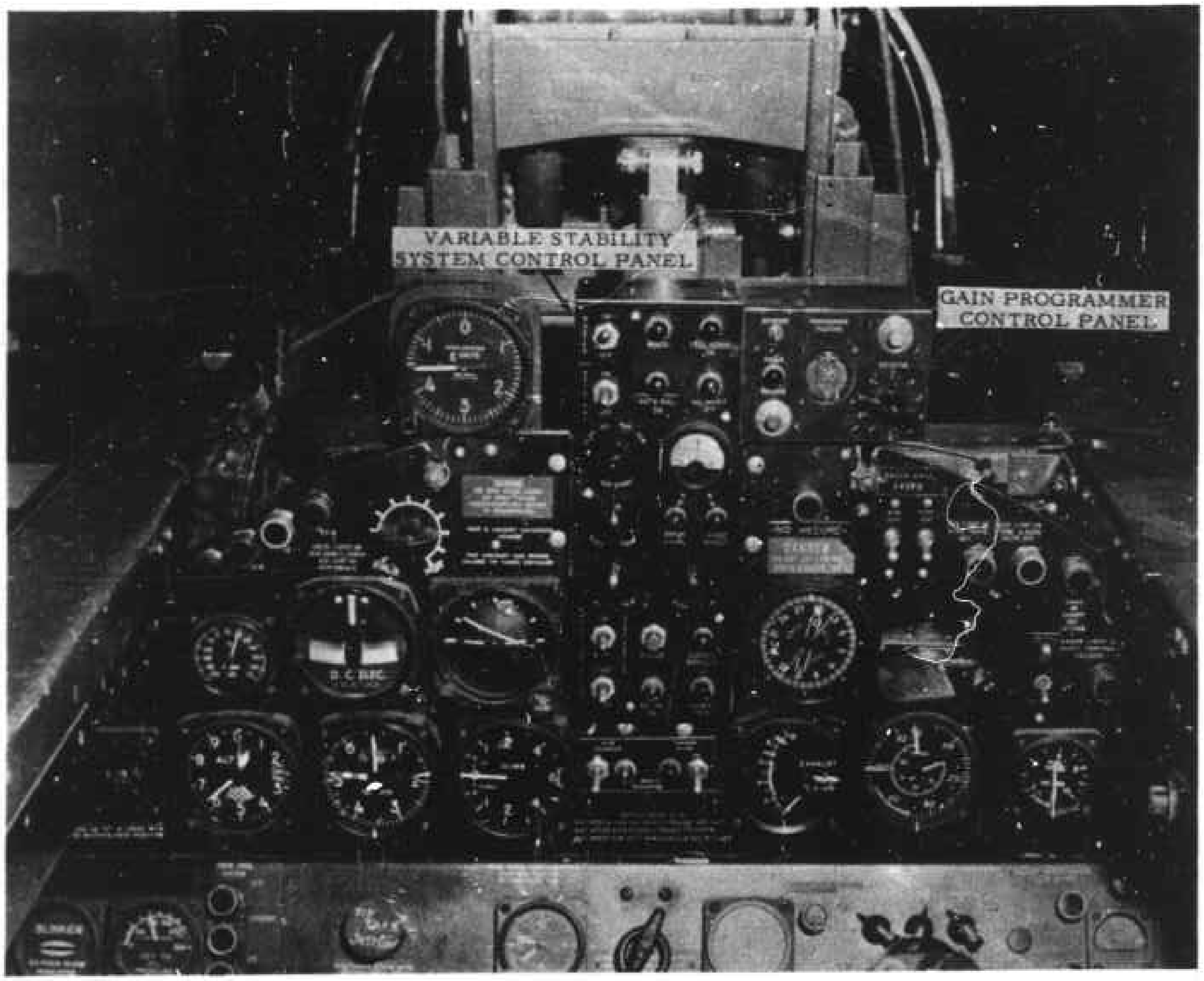


Fig. 2 T-33 safety pilot's cockpit display

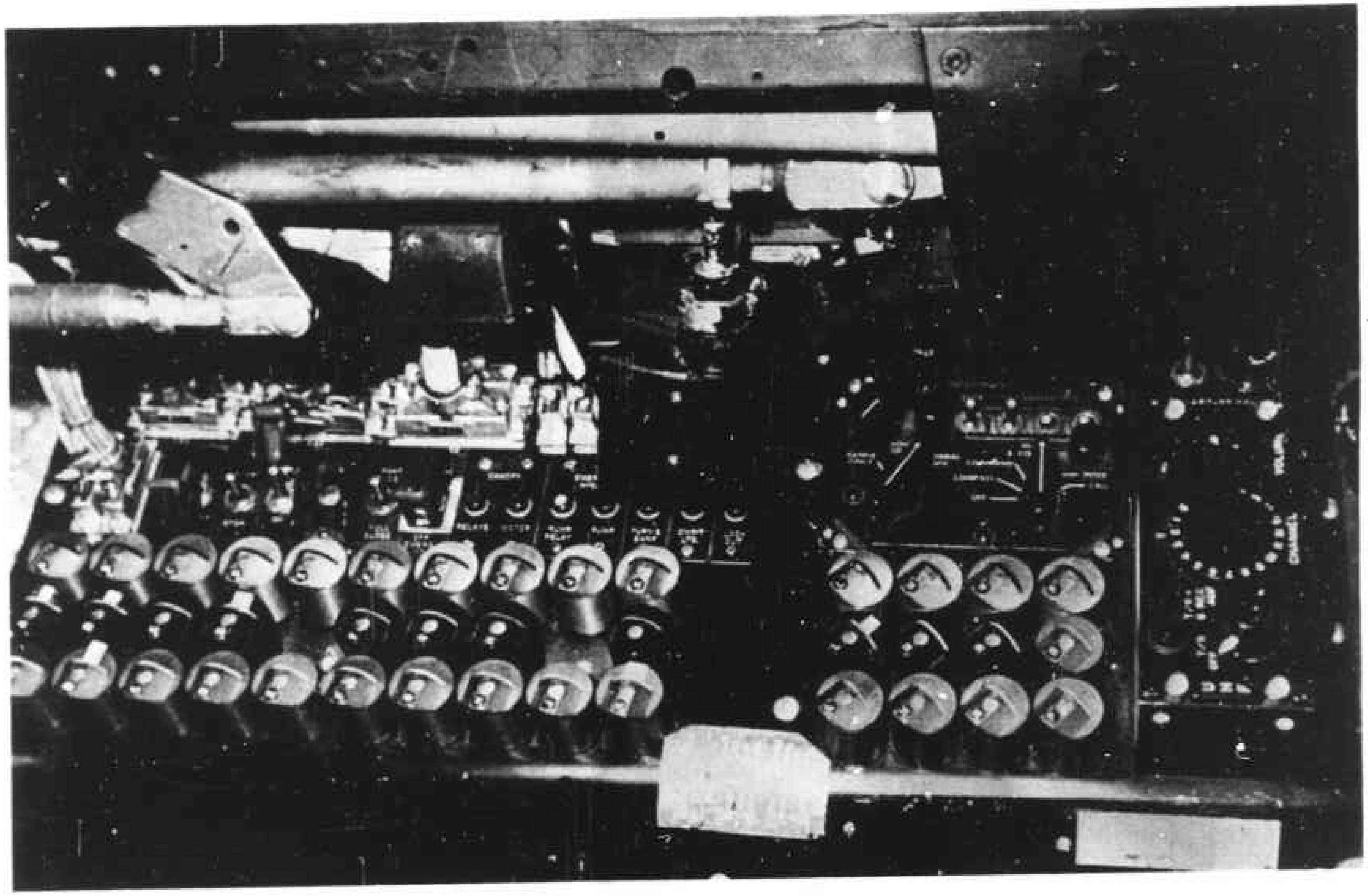


Fig.3 Variable-stability system gain controls

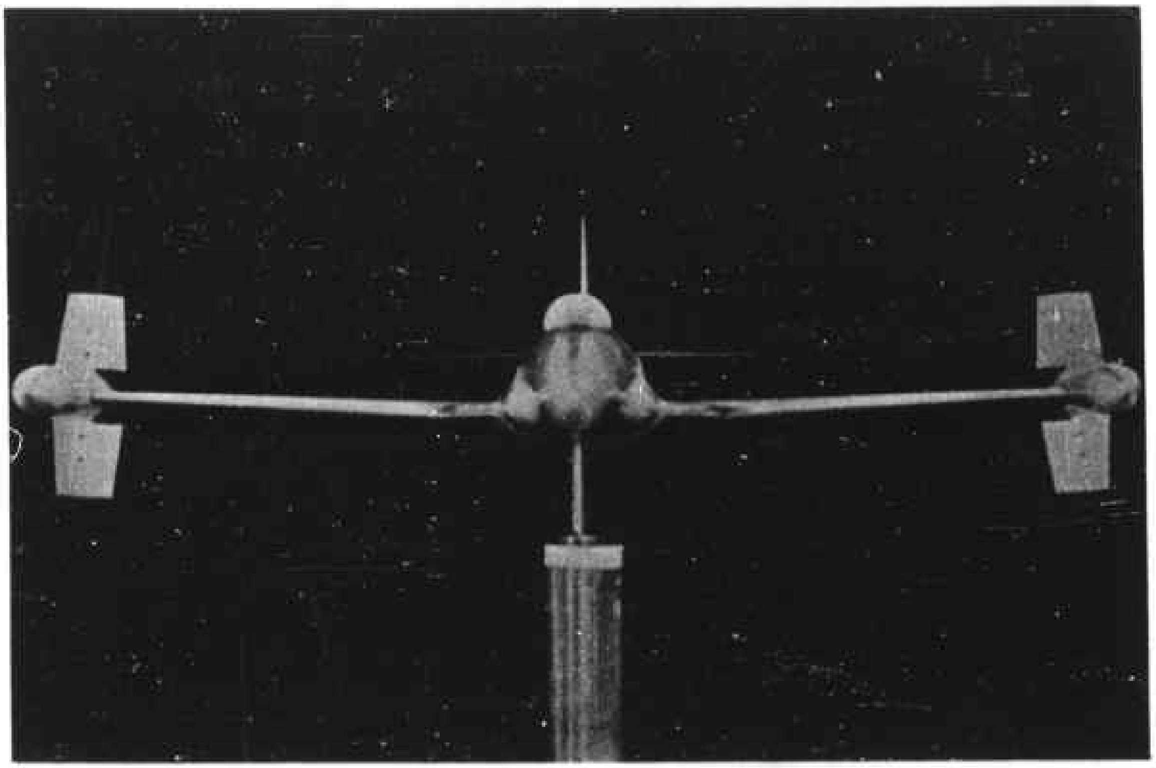


Fig.4 Drag petals installed on T-33 wind tunnel model

Fig. 5 T-33 evaluation pilot's cockpit display

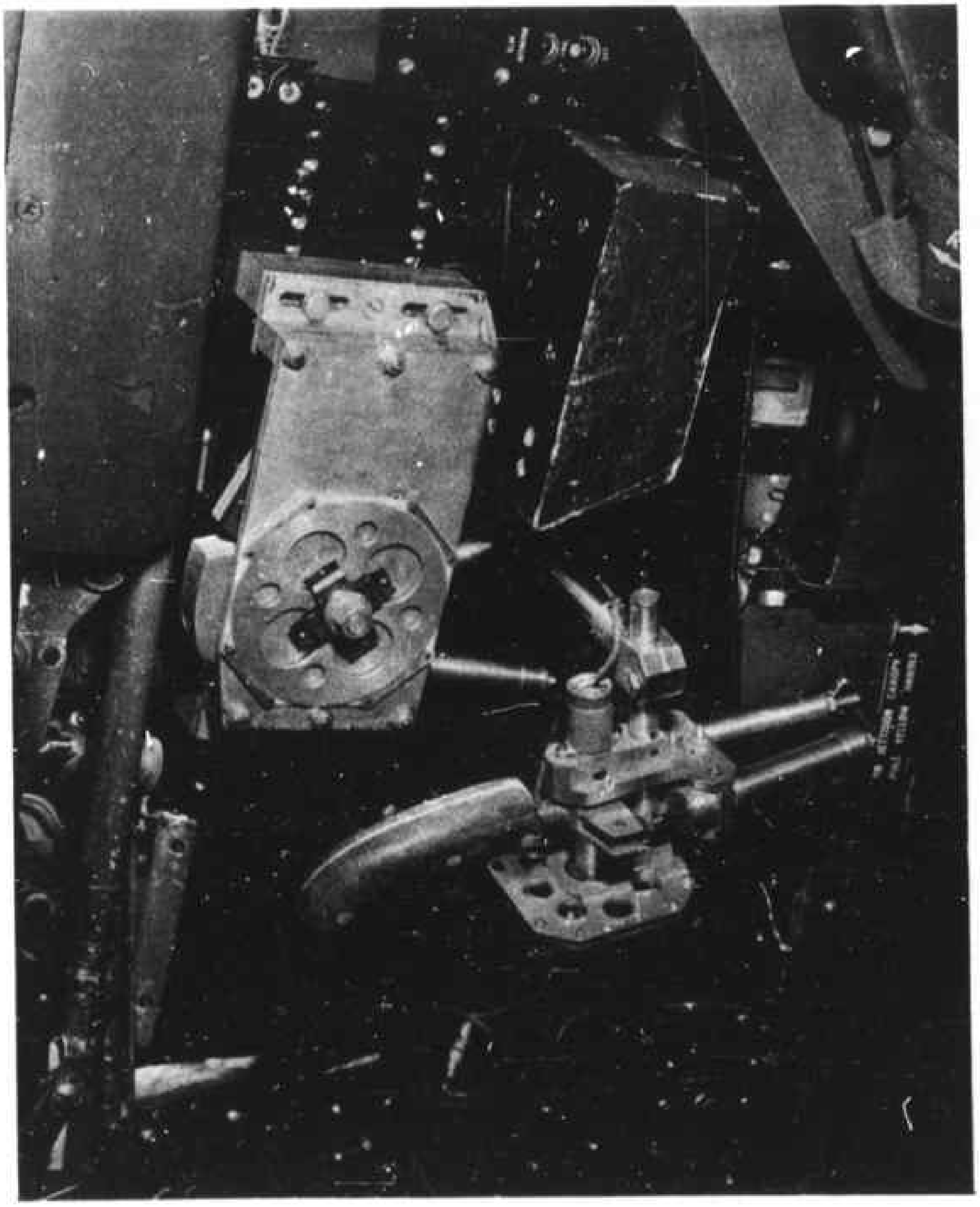


Fig.6 T-33 two-axis side stick controller

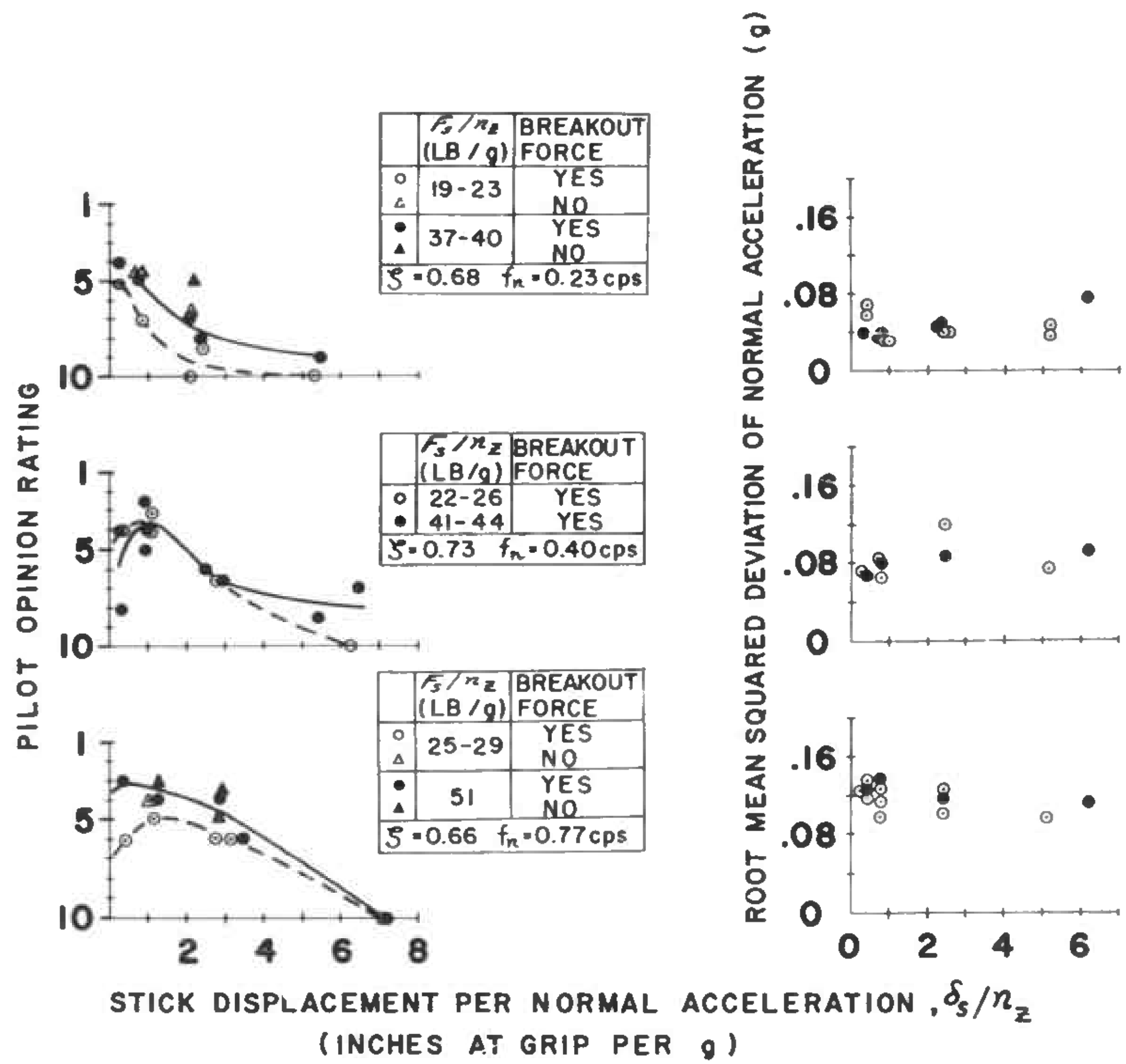


Fig.7 Pilot ratings and performance measures

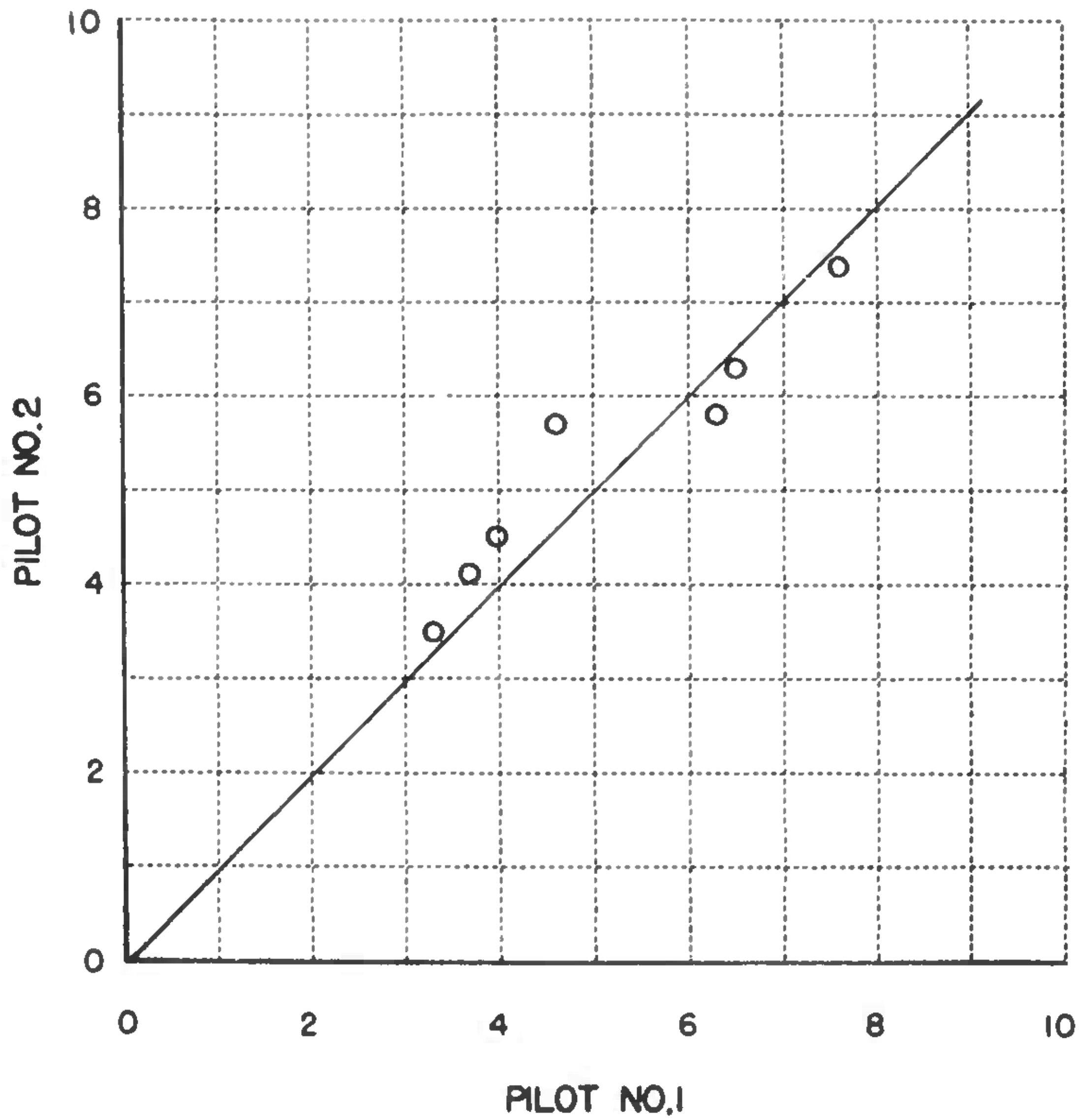
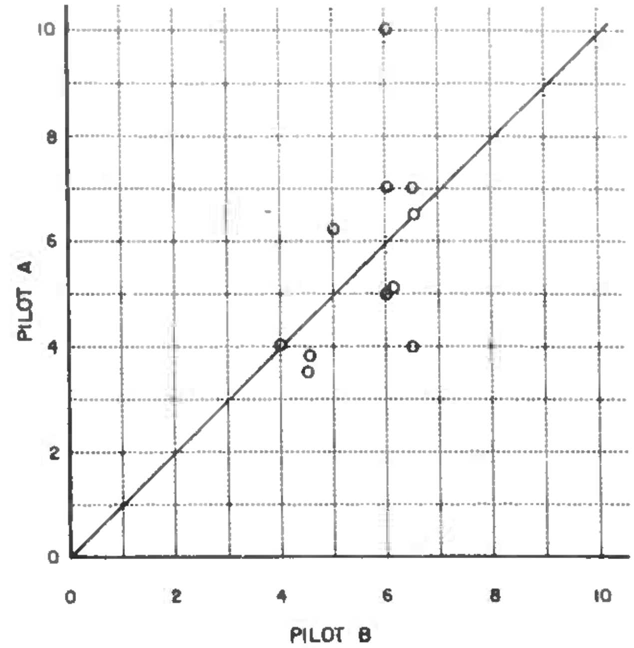
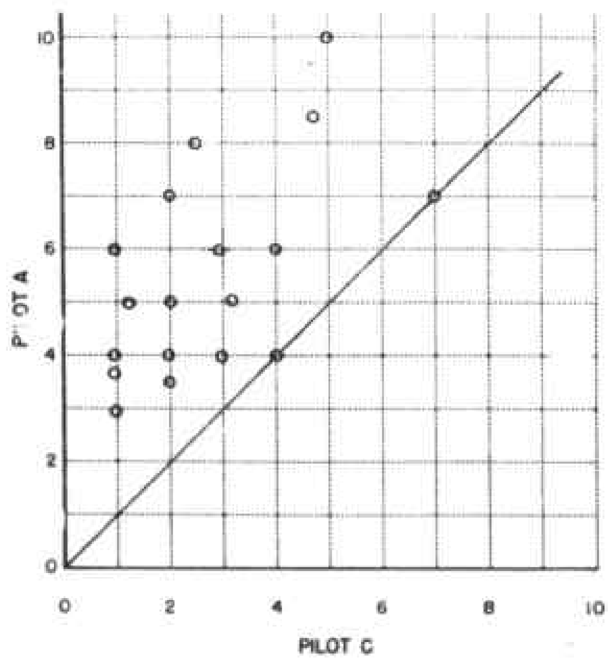


Fig.8 Pilot rating comparison - spiral mode evaluation

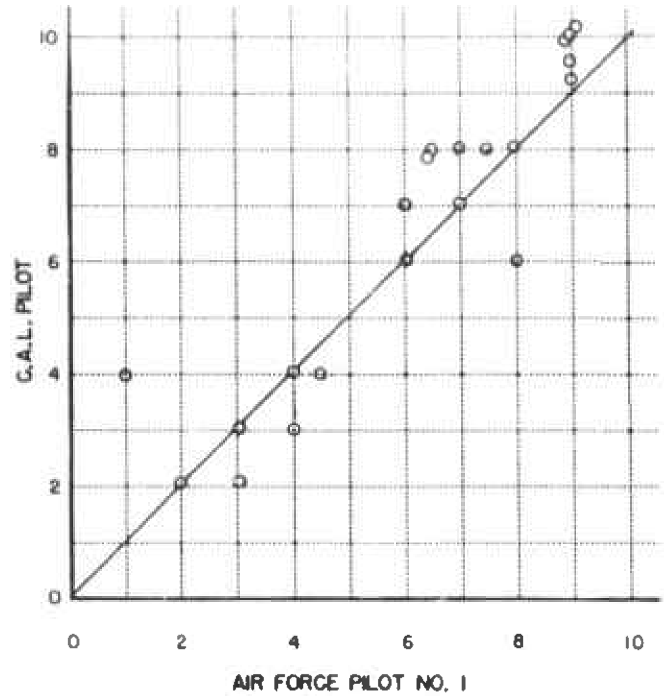


(a) Pilot A vs pilot B

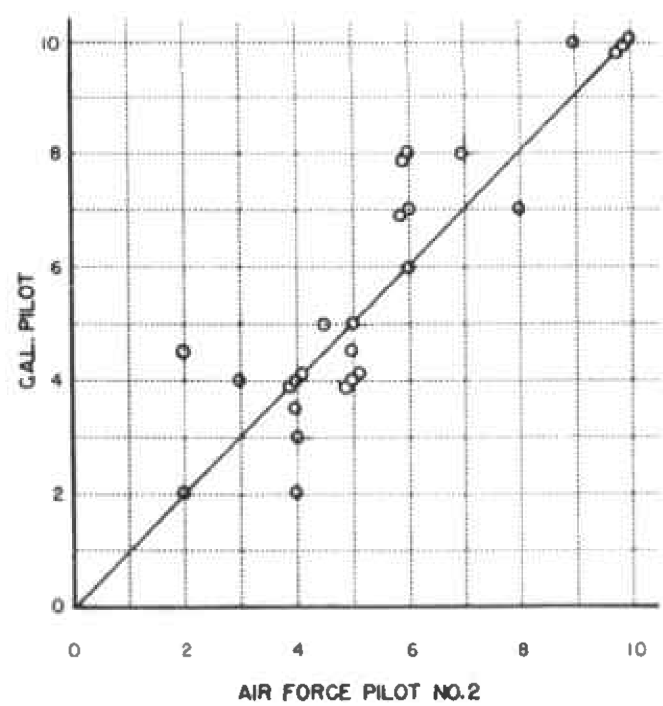


(b) Pilot A vs pilot C

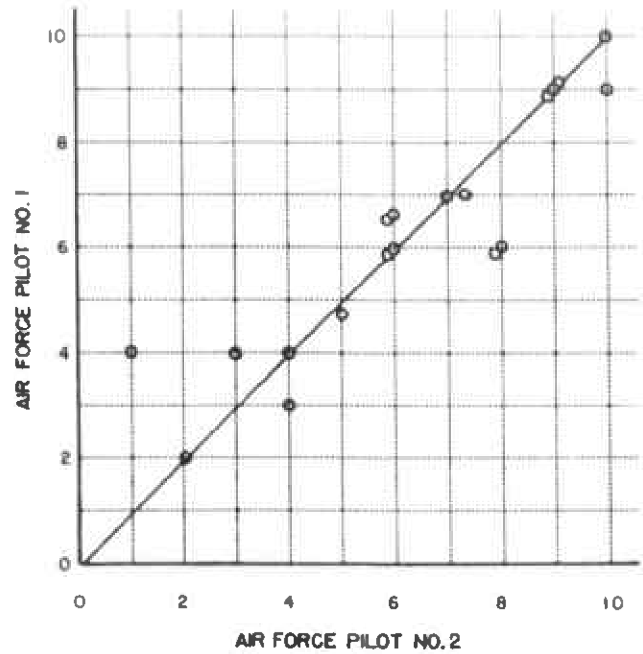
Fig.9 Pilot rating comparison - longitudinal dynamics and stick motion gradient evaluation



(a) CAL pilot vs Air Force pilot No.1



(b) CAL pilot vs Air Force pilot No.2



(c) Air Force pilot No.1 vs Air Force pilot No.2

Fig.10 Pilot rating comparison - longitudinal dynamics evaluation

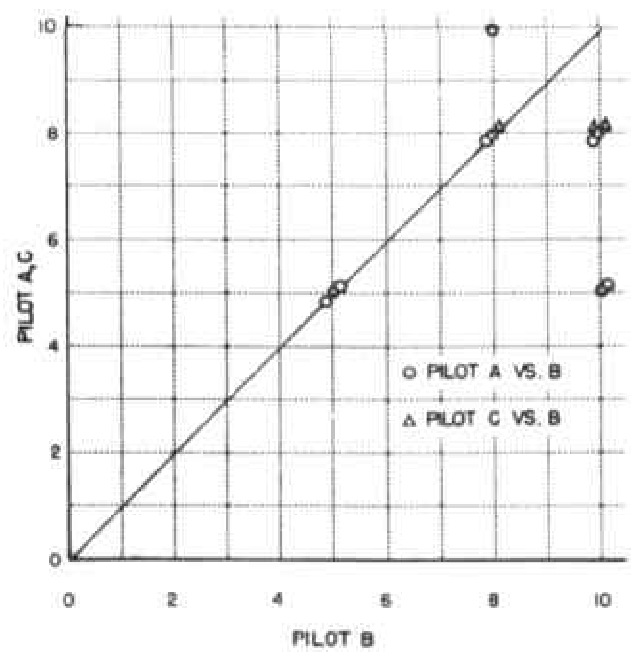


Fig.11 Pilot rating comparison - minimum longitudinal handling-qualities investigation

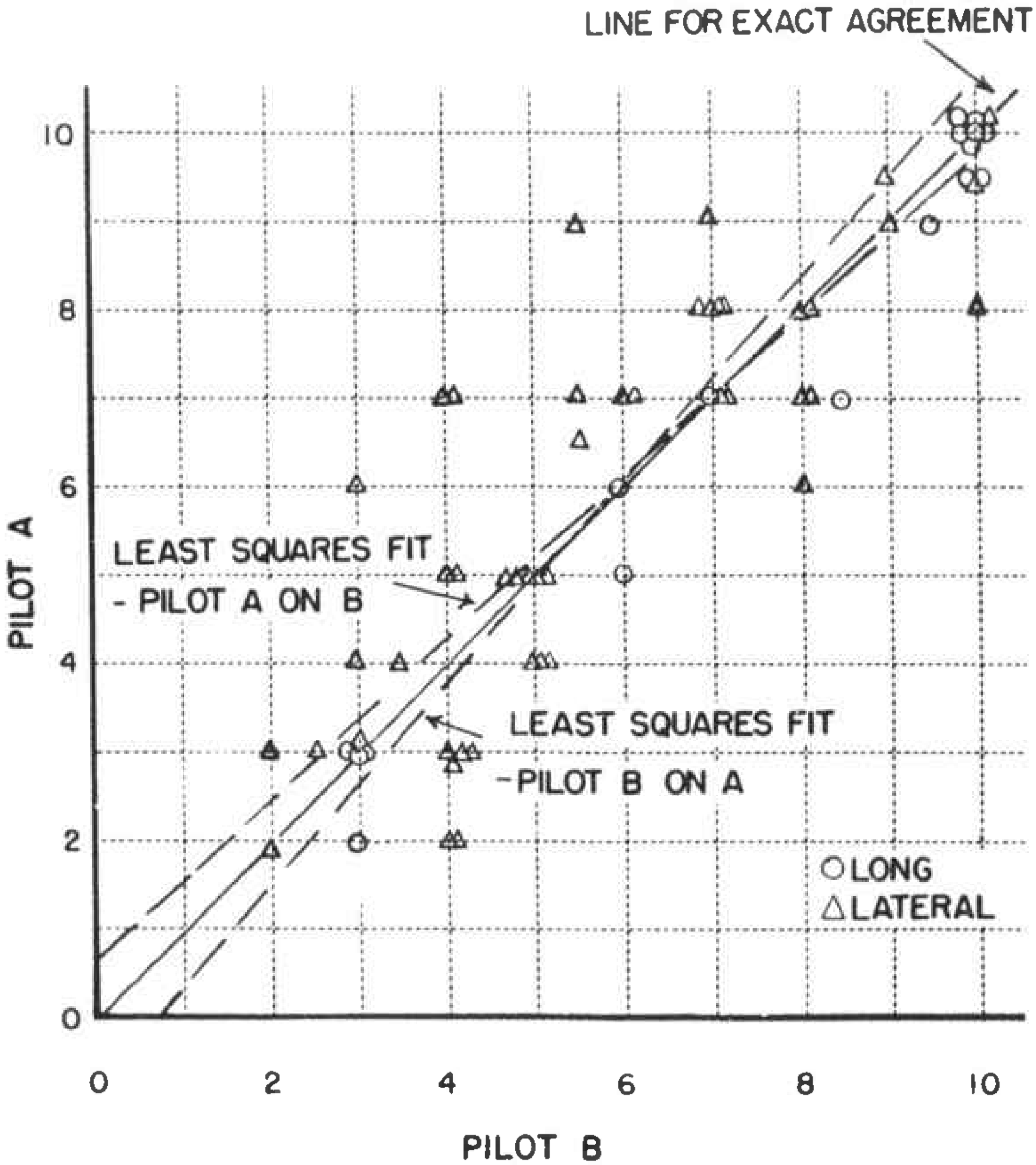


Fig. 12 Pilot rating comparison - fixed-base simulator evaluation of longitudinal and lateral-directional handling qualities

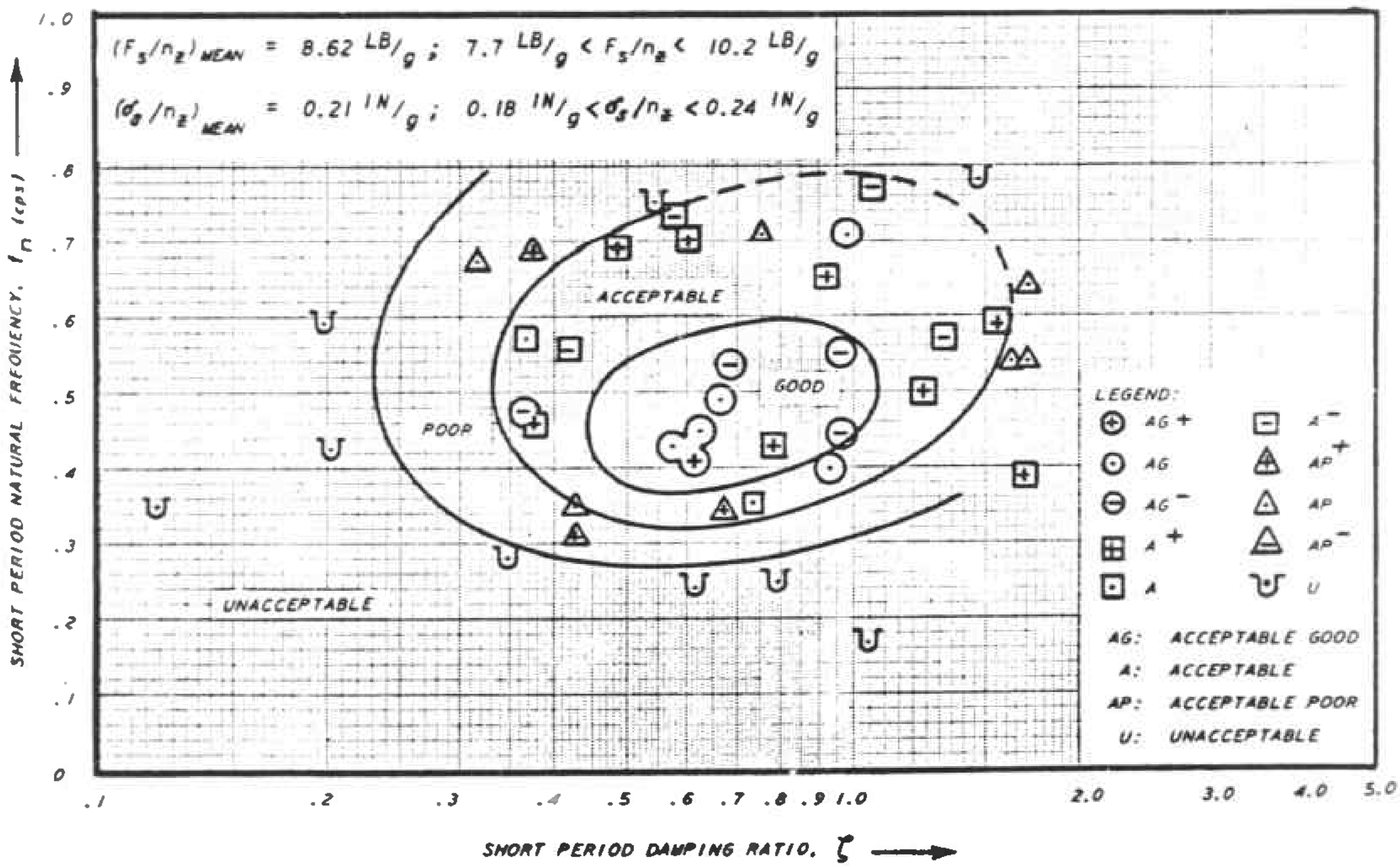


Fig. 13 Short-period pilot opinion ratings

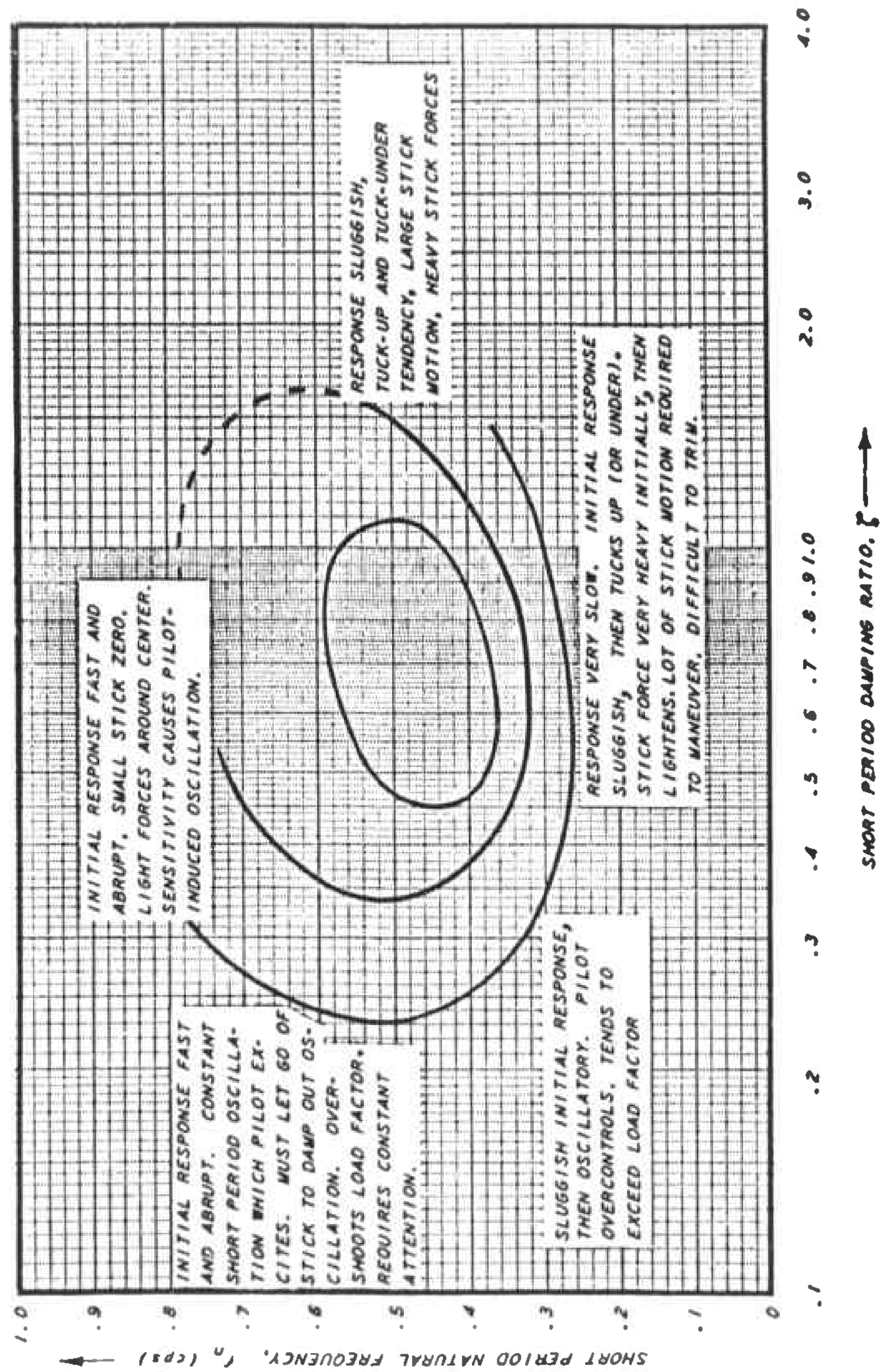


Fig.14 Pilot objections to various short-period dynamics

DISCUSSION

K.H. Doetsch (U.K.): How far does (static) aeroelasticity interfere with the use of the variable-stability aircraft for measuring response to control deflection? Does the compensation, or measurement, of such effects make the process very complicated and eventually very expensive?

Mr. Bull mentioned in his closing sentence that the method could be used to explore the behaviour of the large supersonic aircraft. As I have been worrying about the same problem, I wonder whether Mr. Bull's statement holds also for flight near the ground, i.e. landing and take-off. The low lift slope of the supersonic aircraft leads to large incidence and, incidentally, poor view from the cockpit. The ground effect on lift has been shown by Lean to be up to $\Delta C_L = 0.5$. How could the variable-stability aircraft of large aspect ratio cope?

Reply by E.A. Kidd: The variable-stability airplane is calibrated in flight. For various values of system gain settings the response of the airplane to pilot control stick inputs is measured. It is this response that is matched, by selecting appropriate gain settings, to the airplane or particular configuration being simulated. Thus, in concept, the response of the simulated airplane to pilot control inputs can be matched whatever the underlying causes for the particular response. It would be undesirable to use, as a variable-stability airplane, one that exhibits large non-linearities in its response due to the difficulty in compensating for the effects. However, the T-33 does not suffer in this respect.

Aeroelastic effects, even with the T-33, do limit the maximum gain that can be achieved for particular control deflections per measured response. This results from structural feedback destabilizing that particular control loop. However, these limitations have not in any way limited the use of this aircraft, as these maximum gains are well beyond those required for present and envisioned research.

This particular aspect of a low aspect ratio of supersonic aircraft is a difficult one to simulate with a high aspect ratio airplane. Conceivably, the cockpit itself could be hinged to increase its pitch angle at high C_L, but this does sound complicated. The ground effect on C_L would also be difficult to simulate. Some investigations have suggested that extreme angles of attack may offer such difficulties in the design and operation of the supersonic transport that limitations of angle of attack may be necessary even at the expense of landing speeds and runway lengths. The difficulties referred to relate to landing gear layout, cockpit view, passenger comfort, and so forth. If these limitations should apply, the simulation of the landing operation would be easier.

It should be pointed out that it is possible to vary the lift curve slope through suitable flap actuation as a function of angle of attack. The N.A.S.A. has such a device in a gust alleviation investigation. Other investigations have been made at CAL that have demonstrated the feasibility of this scheme for a variable-stability airplane.

B. McCluney (U.K.): I would like to raise again the question put by Mr. Lean during yesterday's discussion as to the influence of aircraft size on the simulation. If the derivatives and feel are adjusted to provide given aircraft response and control characteristics, these characteristics must be judged in relation to aircraft size. For example, if a large transport aircraft could be made to simulate a high speed fighter, a pilot, having fighter characteristics in the environment of a transport, would find assessment difficult is not impossible. I would think that this factor is more significant in the flying simulator than in the ground simulator, as in the latter case a pilot, experienced in the aircraft type under consideration, knows what comparison to apply and can imagine himself in the environment. Do the authors find that this is a problem or are pilots more adaptive than I give them credit for?

Reply by E.A. Kidd: Mr. McCluney's point is a good one, and it was for exactly that reason that the U.S. Air Force sponsored the development of variable-stability equipment in a jet fighter (F-94A) as well as in a medium bomber (B-26). There were some differences in the characteristics desired by the pilots as obtained with these two airplanes. This difference was most marked in stick force gradients due in large part, however, to the different limit normal accelerations of the two aircraft. The difference in dynamic characteristics may have resulted to a large extent from the different missions and maneuver requirements of the two airplanes. It is this latter factor that is most important. If the pilots are properly orientated with respect to the mission requirements, much of the large airplane-small airplane simulation differences should disappear. We have had considerable success in this regard. There is no denying that over-all cockpit environment including vision capabilities would improve the situation if they could be simulated.

G.H. Lee (U.K.): With regard to the possibilities of simulating a supersonic transport aeroplane by a variable-stability conventional aircraft, it is important to remember that the success or otherwise with which this can be done depends to some degree on the type of supersonic aeroplane being represented. In the case of a slender-wing configuration with separated flow at low speeds, it may well be that some of the vital aerodynamic characteristics are at present unknown. In such circumstances, simulation might be misleading due to lack of fundamental information. In circumstances such as these, it is possibly better to rely on flying simple, small aeroplanes embodying the essential aerodynamics.

Reply by E.A. Kidd: Mr. Lee is correct in pointing out that the simulation can be no better than the information on the vehicle to be simulated. In the case of simulation of an aircraft whose characteristics are not accurately known, the pilot can experience or evaluate characteristics which bracket the expected characteristics. Non-linear characteristics, which might arise from such a phenomenon as separated flow, can be simulated in a variable-stability airplane, although such a requirement does complicate the equipment. However, if the characteristics cannot be predicted with any confidence, then the variable-stability airplane or anything else is no help. It is difficult to see how the essential aerodynamics can be supplied by a single, small aeroplane if they are not in any way predictable.

H.J. Allwright (U.K.): The authors conclude that humans do not differ markedly in their ability to function as aensing and aervo mechaniams, and demonatrate this largely by reference to results achieved in 'aiming' and related tests. This question of the relation between the abilities of test pilots and the 'average' pilot is of fundamental interest to acceptance-evaluation agencies. Another important aspect of it concerns the pilot's powers of anticipation. Especially when operating in 'emergency' with, say, reduced power control, a pilot with poor anticipation might well allow himself to get into a flight condition which would be avoided by pilots superior in this respect, and from then on he would need a higher standard of control; this would have a direct reaction on handling needs for such emergency conditions and I ask, therefore, if research on this aspect is being made?

Reply by E.A. Kidd: If by anticipation Mr. Allwright means the ability of the pilot to foresee an awkward situation arising and taking the necessary steps to avoid or minimize it, then it is agreed that pilots differ considerably in their abilities. This is basically a situation-perceiving and decision-making activity and here experience counts.

If, however, Mr. Allwright means anticipation in the sense of 'leading' control motion to control a machine which may require such a lead or derivative control, then the evidence shows that there is not a great deal of difference in the abilities of different pilots.

There is one aspect of this latter type of control requirement which can bear some elaboration. A skilled pilot, when flying an airplane, is in a situation where he has 'overlearned' the techniques required to control it. He has become highly proficient in the operation and he can set his gains, so to speak, without much experimentation. He can fly the airplane, therefore, without devoting much conscious effort toward the task. This leaves him able to devote his conscious efforts to other aspects of flying. A tyro, on the other hand, has not yet developed the ability to fly his airplane automatically, and must devote a good deal of conscious effort to do so. The addition of another task may swamp him. For example, a student may be able to make landings as well as his instructor in smooth air (I think all instructors will ruefully admit that this is so). However, it takes all the student's attention to do so, while the instructor can do it easily. Add a rough, gusty crosswind to the situation and the picture changes. The instructor can cope with the additional problem, and still perform the landing flare properly. The student cannot, and will bounce the landing in addition to messing up the directional control.

J.C. Wimpenny (U.K.): We have found that the pilot's opinion may change as between immediately after the flight and sometime later when he has had time to think about it further and discuss it with other pilots. Do you take steps to get his immediate reaction without allowing him to discuss it with anyone else first, and then later to obtain a collective view? Do you find his subsequent views differ from his first impressions, and what is your general policy on this question of self-consistency?

Reply by E.A. Kidd: We have a wire recorder installed in the airplane, and the pilot's comments are recorded during flight while his impressions are fresh. Talking is easier than writing, so the wire recorder comments are apt to be more detailed than notes taken on a knee pad. Obtaining comments on the spot is particularly

important if a large number of configurations or conditiona are inveatigated in one flight. If the pilot is required to reconstruct the flight from brief notes, he finds he cannot remember clearly the details of all the different configurations. Recording the pilot's opinions in flight also insures that his opinion ia not influenced by conversation with other pilots. Later diacussion with others may help each pilot to look for things he miased on hia first flight, and may open up hia mind to new viewpointa, but we like to get the raw data unadulterated. When several pilots participate in an evaluation, there is a tendency for the younger or lower ranking people to make their opiniona jibe with the opinions of the others, if they can. Recording comments in flight minimizes both the temptation and the opportunity to do that.

We have found that the pilot'a opinion may change upon consideration of the flight, but that if he is then given a repeat of the matter in question, he will tend to confirm his original view. An exception to this would be the case where he later realizea he did not look into aome particular aspect of the matter, and thinks that it would have been important.

ADDENDUM

AGARD SPECIALISTS' MEETING

on

STABILITY AND CONTROL

Complete List of Papers Presented

Following is a list of the titles and authors of the 41 papers presented at the Stability and Control Meeting held in Brussels in April, 1960, together with the AGARD Report number covering the publication of each paper.

INTRODUCTORY PAPERS

The Aeroplane Designer's Approach to Stability and Control, by G.H.Lee (United Kingdom) .. .. Report 334

The Missile Designer's Approach to Stability and Control Problems, by M.W.Hunter and J.W.Hindes (United States) .. .. Report 335

DESIGN REQUIREMENTS

Flying Qualities Requirements for United States Navy and Air Force Aircraft, by W.Koven and R.Wasicko (United States) .. .. .. Report 336

Design Aims for Stability and Control of Piloted Aircraft, by H.J.Allwright (United Kingdom) .. .. Report 337

Design Criteria for Missiles, by L.G.Evans (United Kingdom) .. Report 338

AERODYNAMIC DERIVATIVES

State of the Art of Estimation of Derivatives, by H.H.B.M.Thomas (United Kingdom) .. .. Report 339

The Estimation of Oscillatory Wing and Control Derivatives, by W.E.A.Acum and H.C.Garner (United Kingdom) .. .. Report 340

Current Progress in the Estimation of Stability Derivatives, by L.V.Malthan and D E.Hoak (United States) .. .. Report 341

Calculation of Non-Linear Aerodynamic Stability Derivatives of Aeroplanes, by K.Gersten (Germany) .. .. Report 342

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AGARD Report 368
North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development
IN-FLIGHT SIMULATION - THEORY AND APPLICATION
Edwin A. Kidd, Gifford Bull and Robert P. Harper, Jr.
1961
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